RESEARCH PAPER

# Fractal Dimensional Analysis of Trabecular Pattern in Mandibular First Molar Edentulous Regions - A Retrospective CBCT Study

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*ABSTRACT*

**Aim:** The study aimed to compare the mean Fractal Dimension of the trabecular patterns in the pre-determined implant sites of 36,46 in the posterior edentulous mandible through CBCT images.

**Methodology:** A retrospective analysis of CBCT images of 200 patients with the age group of 18-68yrs was used to assess the bone quality in 36,46 regions, which were the predetermined implant regions. Coronal, axial, and sagittal sections of the CBCT images of these areas were taken, and Fractal analysis using Image J software was obtained. Data was recorded and statistically analyzed.

**Results:** Statistical analysis revealed significant differences in mean Fractal Dimension between groups 36 (1.5192 ± 0.1262) and 46 (1.4929 ± 0.1249), with a P-value of 0.04. These differences were observed in the axial section across all samples and among males, while in the coronal section, they were found among females.

**Conclusion:** Within the limitations of this study, a statistically significant difference in the trabecular bone architecture was observed between the predetermined implant sites at regions 36 and 46 of the posterior edentulous mandible, as assessed by fractal dimension analysis on CBCT images.

**Clinical Significance:** FDA quantifies and intricate geometric components (fractals) that make up an image in radiodiagnosis. This technique determines the bone trabecular pattern associated with bone quality which may enable us to make better treatment choices and forecast future success quantitatively.

**Keywords:** Cone beam computed tomography, Fractal dimension analysis, Image J, Mandible, Trabecular pattern

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## .Introduction

Fractal analysis (FA), first introduced by Benoît B. Mandelbrot,[1] is a mathematical approach for studying complex natural structures and biological signals. In dentistry, it has been applied to evaluate trabecular bone quality and detect structural changes, proving useful in osteoporosis assessment and in monitoring the diagnosis and progression of periodontitis.[2,3] By quantifying trabecular patterns, FA provides a reliable, non-invasive method for assessing bone density and architecture, thereby supporting diagnostic decision-making.

The fractal dimension (FD) values derived from the box-counting method in trabecular bone typically range between 1 and 2. Values approaching 2 indicate a more intricate and heterogeneous bone microstructure, whereas values closer to 1 reflect a simpler architecture characterized by increased porosity. This quantitative measure has also been correlated with implant insertion torque and resonance frequency values, further underscoring its clinical relevance.Fractal dimension analysis has emerged as a valuable adjunct in implantology because it bridges radiographic assessment with biomechanical outcomes. By quantifying trabecular complexity, FD values not only reflect bone quality but also correlate with clinical parameters such as insertion torque and resonance frequency, which are critical indicators of primary implant stability.This relationship highlights the potential of FD analysis to serve as a predictive tool in treatment planning, enabling clinicians to anticipate osseointegration success. Integrating FD evaluation with CBCT imaging therefore provides a comprehensive, non-invasive approach to assessing bone microarchitecture prior to implant placement.[4]

FA can be performed using conventional imaging modalities, such as intraoral radiographs and orthopantomograms, or advanced techniques including cone-beam computed tomography (CBCT), micro-computed tomography (micro-CT), multislice computed tomography, high-resolution peripheral quantitative computed tomography, and high-resolution magnetic resonance imaging (HR-MRI).[4]

Medullary bone adapts to functional loading, with trabecular architecture and bone mineral density (BMD) serving as key indicators of skeletal health. Dual-energy X-ray absorptiometry (DEXA) remains the gold standard for bone density evaluation; however, its dental application is limited by technical challenges and the absence of cross-sectional imaging of maxillofacial regions.[5] CBCT provides three-dimensional imaging and site-specific assessment of jawbone density, positioning it as a promising alternative to conventional radiographic methods.Furthermore, CBCT is increasingly acknowledged as a valuable modality in oral and maxillofacial imaging due to its enhanced accessibility for dental professionals, compact technology, reduced radiation exposure, and lower cost.[6]

Image analysis enhances treatment planning and predictability in implantology. Measurements of mandibular and maxillary bone guide clinical decisions and forecast outcomes. Among these methods, FD analysis is particularly valuable. By quantifying trabecular geometry, FD enables radiodiagnosis of bone quality. Studies have shown that FD measurements in periapical radiographs can detect subtle peri-implant changes,[7] with similar results reported in panoramic and CBCT imaging. This underscores the versatility and diagnostic potential of FA in dentistry.

Despite these advances, research on bone microarchitecture remains limited, highlighting the need for further studies. Elani et al. reported that dental implant use is rising, with an annual growth rate of approximately 14%.[8] Lee CT and colleagues, in their systematic review, found that peri-implant diseases are highly prevalent.[9] These findings suggest that evaluating bone microarchitecture may help identify potential complications prior to implant placement. Accordingly, the present study was designed to assess alterations in the trabecular microarchitecture of the mandibular posterior edentulous regions (sites 36 and 46) using CBCT with FD analysis.

## Material and Methods

This retrospective study utilized anonymized CBCT radiographic data of patients of Indian origin, in ramaiah university, Karnataka ,collected over a six-month period from the month march to august 2025. Ethical clearance was obtained from the Institutional Review Board prior to commencement. Only patients free from systemic or local disorders that could affect jawbone structure were included. CBCT images of edentulous areas at sites 36 and 46 with completely healed sockets following extraction were considered. Patients with evident periodontal or osseous pathology, or scans with significant radiographic errors, were excluded. The final study sample comprised 200 individuals aged 19–68 years, representing both genders.

From each CBCT scan, sagittal, coronal, and axial sections were selected for fractal dimension (FD) analysis using ImageJ software (version 1.53a, National Institutes of Health, Bethesda, MD, USA). After applying inclusion and exclusion criteria, approximately 200 images were retained for analysis. To minimize inter-observer variability, two oral radiologists were trained and calibrated, achieving 90% agreement prior to evaluation. Both radiologists independently assessed all eligible CBCT images according to standardized criteria.

All scans were acquired using a Carestream C9300 CBCT machine under uniform exposure parameters (74 kVp, 12 mA). Trabecular patterns in the posterior edentulous regions on both the right (tooth 46) and left (tooth 36) sides were analyzed. FD values obtained from the selected sections were tabulated and subjected to statistical analysis.

### Fractal Analysis and Region of Interest (ROI) Selection

In the software's "area defining" box, a 40 × 120 square unit ROI was selected for the edentulous regions at positions 36 and 46.

### Image Processing and Pattern Extraction

Trabecular bone patterns were extracted using the algorithm described by Geraets et al.[7],[8] and White et al.[9] FD, trabecular intensity, and particle size were measured in all ROIs. The selected area was processed using the method designed by White and Rudolph.

To determine FD, the ROI images underwent a series of steps including blurring, subtraction, addition, binarization, erosion, dilation, inversion, skeletonization, and superimposition.[9,10] Images were first blurred with a Gaussian filter to remove large-scale variations. The blurred image was then subtracted from the original, and 128 gray levels were added to each pixel of the resultant image. A threshold of 128 gray levels was applied, converting the image into binary format that segmented bone (gray level 255) and marrow (gray level 0). Finally, mathematical morphological operators were used to extract the outline and skeletonized version of the binary image (Figures 1–5).

Statistical Analysis

FD values from the predetermined implant regions (36 and 46) were tabulated and analyzed using SPSS software (version 22, IBM Corp., Armonk, NY, USA). The mean FD between sites 36 and 46 was compared across samples, gender groups, and CBCT sections using the Mann–Whitney U test. A significance level of $p < 0.05$ was considered statistically significant, while $p < 0.001$ was regarded as highly significant.

Results

The CBCT images analyzed were from patients aged 18–68 years, with a mean age of 45.40 ± 13.46. The distribution of patient images was equal between the 36 (n = 100) and 46 (n = 100) regions, with an equal representation of males (n = 50) and females (n = 50) in each group (Table 1).

In the sagittal section, tooth 36 had a mean FD of 1.5377 ± 0.1471, while tooth 46 had a mean FD of 1.5408 ± 0.1157. The difference between the two sites was not statistically significant. In the axial section, tooth 36 demonstrated a higher mean FD value of 1.5192 ± 0.1262 compared to tooth 46, which had a mean FD of 1.4929 ± 0.1249. This difference was statistically significant. In the coronal section, tooth 36 had a mean FD of 1.5302 ± 0.1630, while tooth 46 showed a slightly higher value of 1.5457 ± 0.1235, with no significant difference observed. Overall, the Mann–Whitney test revealed a statistically significant difference in the axial section between teeth 36 and 46 (Table 2).

Gender-specific comparisons revealed further variations. Among male participants, a significant difference was observed between teeth 36 and 46 in the axial section (Table 3). In female participants, a significant difference was noted between teeth 36 and 46 in the coronal section (Table 4). Gender-wise comparison of tooth 36 revealed a highly significant difference in the coronal section (Table 5).

The comparison of mean trabecular intensity between teeth 36 and 46 across sagittal, axial, and coronal sections revealed no statistically significant differences in the overall sample. Among male subjects, all $p$-values exceeded 0.05, indicating no significant variation in trabecular intensity between the left and right mandibular first molars. Similarly, female subjects showed no statistically significant differences in trabecular intensity between teeth 36 and 46 across all sections. Gender-wise comparisons further demonstrated that trabecular intensity in tooth 36 did not differ significantly between males and females, with all $p$-values above 0.05. Likewise, tooth 46 showed no significant gender-based differences in trabecular intensity across the examined regions.

**Discussion**

The trabecular architecture of bone is evaluated through radiographic imaging.[11] High-resolution CBCT has been shown to be comparable to two-dimensional histology and micro-CT in assessing bone morphometric parameters such as trabecular number, thickness, separation, and bone volume fraction.[12,13] Fractal dimension (FD) analysis has been widely used to assess trabecular bone structure and biomechanical quality, and existing literature indicates that radiomorphometric indices and FD analysis using CBCT remain areas for further exploration.[14] Previous studies recommended a minimum sample size of at least 25 per group and a slice thickness of 25 mm, as this allowed the inclusion of more image slices and closely resembled a two-dimensional panoramic radiograph. In the present study, trabecular architecture in the mandibular posterior region of teeth 36 and 46 was examined using CBCT images with a slice thickness of 20 mm, with 100 samples per group. Bone quality relies significantly on trabecular microarchitecture; therefore, evaluating trabecular patterns was crucial for successful osseointegration and effective bone healing in relation to dental implants.[15-18]

Mandibular first molars are the most commonly missing teeth in the oral cavity.[19] As the earliest permanent teeth to erupt, they were exposed to the oral environment for the longest duration, making them highly susceptible to developmental disturbances such as hypomineralization. Their anatomical position and occlusal morphology predisposed them to plaque accumulation, increasing vulnerability to periodontitis. They were also prone to caries activity due to early eruption and functional load, often resulting in premature tooth loss. Hence, mandibular first molars (36 and 46) provided clinically relevant and representative sites for evaluating bone quality and related dental conditions.

In the study of Hegde MN et al, FD analysis was performed in regions mesially, distally, and apically adjacent to the predefined implant placement sites of 36 and 46, ensuring that the analysis covered clinically relevant areas. This approach provided a comprehensive understanding of bone structure and fractal dimensions in the selected regions, which can be crucial for implant planning and assessment. Although some studies recommended panoramic radiographs for evaluating trabecular structures, citing lower image resolution and higher radiation dose associated with CBCT,[19] our findings highlighted the added value of CBCT in this context. FD analysis of CBCT images revealed statistically significant differences across multiple regions of interest and sections examined, demonstrating the capability of CBCT to provide meaningful insights into trabecular bone patterns despite its limitations. Importantly, CBCT imaging avoided the superimpositions commonly encountered in orthopantomographs (OPGs), thereby offering clearer visualization of site-specific trabecular architecture. These results contributed to the growing body of literature supporting the utility of FD analysis applied to CBCT images in dental research and clinical practice.

The present study found no statistically significant differences in trabecular bone intensity between teeth 36 and 46 across sagittal, axial, and coronal regions, suggesting bilateral symmetry in mandibular first molars. This pattern was consistent across both male and female subgroups, indicating that gender did not influence trabecular architecture in either tooth within the sampled population. These findings aligned with previous studies of Fujita Y, et al. reporting minimal asymmetry in mandibular trabecular patterns and limited sex-based variation in bone microstructure, [20–25] The absence of significant differences may have reflected uniform biomechanical loading and adaptive remodeling in the posterior mandible, reinforcing the reliability of using either side for diagnostic imaging or morphometric analysis in clinical and research settings.

Overall, findings from this study indicated site- and sex-specific variations in bone quality, emphasizing the usefulness of fractal analysis as a non-invasive tool for evaluating trabecular bone patterns during pre-implant assessment. Incorporating FD analysis may aid clinicians in more accurate implant planning and risk assessment in the posterior mandible.

Most previous studies evaluated FD on periapical, bitewing, and panoramic radiographs [7]. In recent years, the number of studies applying FD analysis to CBCT images has increased; however, such studies remain limited. Therefore, the present study contributed to the existing body of literature by expanding the application of FD analysis to CBCT images, providing additional evidence for its utility in assessing trabecular bone architecture.

The present study underscores the clinical relevance of fractal dimension (FD) analysis applied to CBCT images in evaluating trabecular bone quality prior to implant placement. By quantifying trabecular complexity, FD values provide insight into bone microarchitecture that correlates with implant stability parameters such as insertion torque and resonance frequency.[10] This relationship highlights FD analysis as a valuable adjunct to conventional radiographic assessment, enabling clinicians to anticipate osseointegration success, select appropriate implant sites, and improve risk assessment. Integrating FD evaluation into routine pre-implant planning may therefore enhance diagnostic accuracy and contribute to long-term treatment predictability.

Several strengths support the reliability of this study. The inclusion of 200 patients provided robust statistical power compared to earlier studies that recommended smaller sample sizes.[14] Standardized CBCT acquisition parameters and calibration of radiologists minimized inter-observer variability, while site-specific analysis of mandibular first molars ensured clinical relevance, as these teeth are frequently missing and commonly replaced with implants.[19] Gender-based comparisons further enriched the analysis by exploring potential biological variations in trabecular architecture. Importantly, the study expanded the application of FD analysis beyond conventional radiographs, contributing to the growing evidence base for CBCT in bone quality assessment.

Nonetheless, certain limitations must be acknowledged. The retrospective design restricted control over patient selection and clinical variables, while the single-population sample of Indian origin may limit generalizability to other ethnic groups. The slice thickness of 20 mm, although adequate, differed slightly from the 25 mm recommended in prior studies,[14] which may affect comparability. Additionally, the study did not directly correlate FD values with clinical outcomes such as implant success or failure, leaving scope for future prospective investigations. Finally, only CBCT imaging was assessed, without comparison to other advanced modalities such as micro-CT or HR-MRI, which could provide further validation.

## Conclusion

The comparison of mean fractal dimension (FD) values between mandibular first molars (36 and 46) revealed statistically significant differences in the axial section for the overall sample and among male participants, as well as in the coronal section among female participants. These findings strengthen the evidence supporting the effectiveness of FD analysis using CBCT images for trabecular bone evaluation. The absence of significant differences in trabecular intensity across sites and genders further suggests bilateral symmetry and uniform biomechanical loading in the posterior mandible.

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| **Age and gender distribution among 2 groups** | | | | | | |
|---|---|---|---|---|---|---|
| Variable | Category | Tooth 36 | | Tooth 46 | | p-value |
| | | Mean | SD | Mean | SD | |
| Age | Mean | 43.90 | 12.07 | 45.40 | 13.46 | 0.30[a] |
| | Range | 21 – 67 | | 19 – 68 | | |
| | | n | % | N | % | |
| Sex | Males | 50 | 50 % | 50 | 50 % | 1.00[b] |
| | Females | 50 | 50 % | 50 | 50 % | |

**Note:** a. Mann Whitney Test & b. Chi Square Test

Table 1. **Age and gender distribution among 2 groups**

| **Comparison of mean Fractal Dimension between Tooth 36 & 46 at different regions in overall samples using Mann Whitney Test** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Section | Tooth | N | Mean | SD | Mean Ranks | Z | p-value |
| Sagittal | Tooth 36 | 100 | 1.5377 | 0.1471 | 99.95 | -0.136 | 0.89 |
| | Tooth 46 | 100 | 1.5408 | 0.1157 | 101.06 | | |
| Axial | Tooth 36 | 100 | 1.5192 | 0.1262 | 108.52 | -1.958 | 0.04* |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Tooth 46 | 100 | 1.4929 | 0.1249 | 92.49 | | |
| Coronal | Tooth 36 | 100 | 1.5302 | 0.1630 | 96.22 | -1.047 | 0.30 |
| | Tooth 46 | 100 | 1.5457 | 0.1235 | 104.79 | | |

* - Statistically Significant

Table 2. Comparison of mean Fractal Dimension between 36 & 46 at different regions in overall samples

| **Comparison of mean Fractal Dimension between Tooth 36 & 46 at different regions among males using the Mann-Whitney Test** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Section | Tooth | N | Mean | SD | Mean Ranks | Z | p-value |
| Sagittal | Tooth 36 | 50 | 1.5591 | 0.1406 | 54.94 | -1.531 | 0.13 |
| | Tooth 46 | 50 | 1.5216 | 0.1018 | 46.06 | | |
| Axial | Tooth 36 | 50 | 1.5270 | 0.0937 | 56.00 | -1.996 | 0.04* |
| | Tooth 46 | 50 | 1.4850 | 0.1077 | 45.00 | | |
| Coronal | Tooth 36 | 50 | 1.5784 | 0.1399 | 52.51 | -0.693 | 0.49 |
| | Tooth 46 | 50 | 1.5546 | 0.0966 | 48.49 | | |

* - Statistically Significant

Table 3. Comparison of mean Fractal Dimension between Tooth 36 & 46 at different regions among males

| **Comparison of mean Fractal Dimension between Tooth 36 & 46 at different regions among Females using Mann Whitney Test** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Section | Tooth | N | Mean | SD | Mean Ranks | Z | p-value |
| Sagittal | Tooth 36 | 50 | 1.5162 | 0.1516 | 46.15 | -1.499 | 0.13 |
| | Tooth 46 | 50 | 1.5600 | 0.1262 | 54.85 | | |
| Axial | Tooth 36 | 50 | 1.5114 | 0.1526 | 53.26 | -0.951 | 0.34 |
| | Tooth 46 | 50 | 1.5008 | 0.1406 | 47.74 | | |
| Coronal | Tooth 36 | 50 | 1.4819 | 0.1713 | 44.64 | -2.020 | 0.04* |
| | Tooth 46 | 50 | 1.5369 | 0.1460 | 56.36 | | |

* - Statistically Significant

Table 4. Comparison of mean Fractal Dimension between Tooth 36 & 46 at different regions among Females

| **Gender-wise comparison of mean Fractal Dimension in Tooth 36 at different regions using Mann Whitney Test** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Section | Gender | N | Mean | SD | Mean Ranks | Z | p-value |
| Sagittal | Males | 50 | 1.5591 | 0.1406 | 54.79 | -1.479 | 0.14 |
| | Females | 50 | 1.5162 | 0.1516 | 46.21 | | |
| Axial | Males | 50 | 1.5270 | 0.0937 | 49.72 | -0.269 | 0.79 |
| | Females | 50 | 1.5114 | 0.1526 | 51.28 | | |
| Coronal | Males | 50 | 1.5784 | 0.1399 | 59.48 | | 0.002* |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Females | 50 | 1.4819 | 0.1713 | 41.52 | -3.096 | |

* - Statistically Significant

Table 5. Gender-wise comparison of mean Fractal Dimension in Tooth 36 at different regions

Fig 1

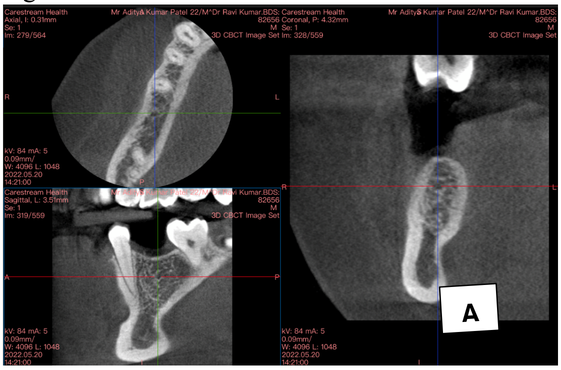
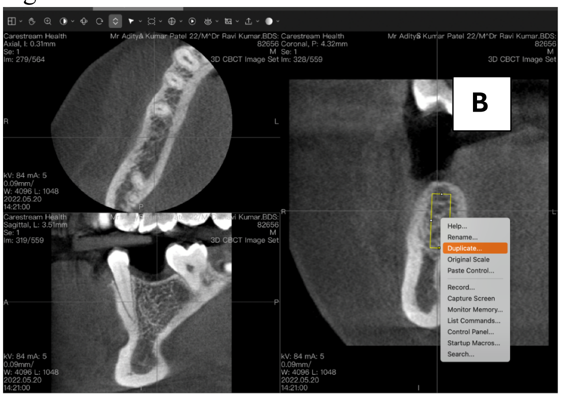


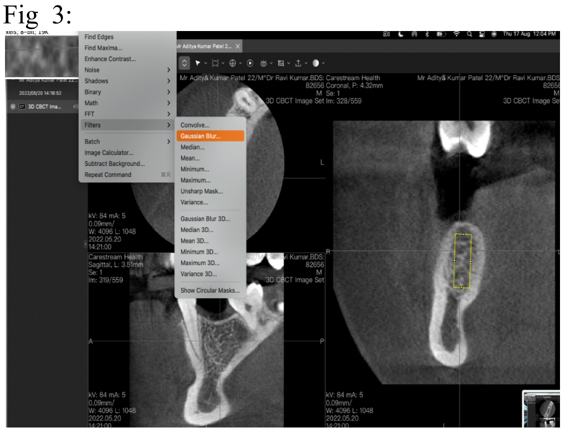

Figure 1: CBCT images of mandible A)Axial Section of left first molar region B)Sagittal Section of lt first molar region C) Coronal Section of lt first st molar region

Fig 2:



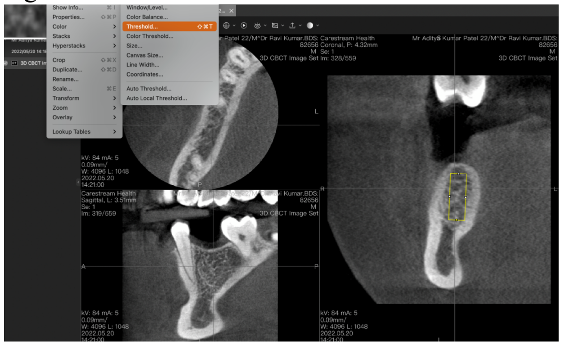

- Fig 2: Selection of ROI of left 1 st molar region in sagittal section of the CBCT image was blurred using a Gaussian filter to remove large-scale variations on the image using image J software.

Fig 3:

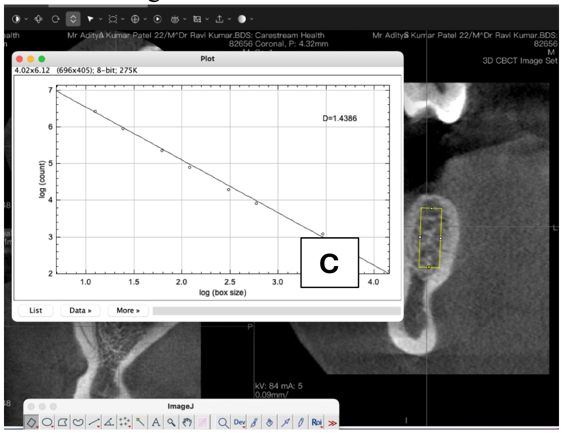


- Fig 3: The blurred image (low pass filtered image) of left 1$^{st}$ molar region in sagittal section of CBCT was then subtracted from the original image, and 128 gray levels were added to each pixel of the subtraction image using image J software.

Fig 4:



- Fig 4: The binary image of left 1$^{st}$ molar region, in sagittal section of CBCT was obtained by thresholding on a gray level of 128, which segmented the image into the bone (gray level of 255) and marrow (gray level of 0) using image J software.
- Fig 5:




- Fig 5 :The outline and skeletonized image of 1$^{st}$ left molar region, in sagittal section of CBCT were extracted from the binary image by mathematical morphologic operators to get D Values image J software.